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## RESULTS FROM MEDIUM-ENERGY INTRANUCLEAR-CASCADE CALCULATION\*

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### Abstract

An appreciable quantity of data has been generated using a medium-energy intranuclear-cascade calculation. Reactions were calculated for incident neutrons, protons, and charged pions on five elements ranging from oxygen to lead. The energy range of the incident nucleons was from 500 to 3000 MeV in 500-MeV steps and, similarly, the energy range of the incident pions was from 500 to 2500 MeV. Data from the cascade and evaporation phases are available. A preliminary version of the computer programs used to generate the data is also available. The final version of the programs will be made available in the near future.

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## 1. INTRODUCTION

A substantial quantity of data has been generated by the method of intranuclear cascades. The program used to generate these data is MECC-7 (Medium Energy Cascade Calculation, version 7). An evaporation program<sup>1)</sup> was used to carry the nuclear reaction through the evaporation phase, and hence data are available for both the cascade and evaporation phases of the reaction.

The reactions calculated were incident protons and neutrons at 500, 1000, 1500, 2000, 2500, and 3000 MeV and incident  $\pi^+$ - and  $\pi^-$ -mesons at 500, 1000, 1500, 2000, and 2500 MeV on  $^{16}\text{O}$ ,  $^{27}\text{Al}$ ,  $^{65}\text{Cu}$ ,  $^{100}\text{Ru}$ , and  $^{207}\text{Pb}$ . These data are extensions to higher energies of reactions that were calculated previously at 25 to 400 MeV<sup>2)</sup>.

A preliminary version of the cascade code, MECC-3, along with the evaporation codes and other editing codes, is also available. The code MECC-3 was used to generate data for comparisons with experiments involving incident nucleons and emitted nucleons, and reasonable agreement was found<sup>3)</sup>. The differences between MECC-3 and MECC-7 are that the latest  $\pi$ -nucleon cross sections were not used in MECC-3 whereas they are in MECC-7 and that the angular distribution of the isobars<sup>3)</sup>, utilized in calculating the pion-production reactions, was taken to be isotropic 50% of the time, forward 25% of the time, and backward 25% of the time in MECC-3, whereas it was taken to conform more to the experimental data over the energy range considered in MECC-7<sup>4)</sup>. This involved varying the combinations of isotropic and forward-backward with energy and reaction. The combinations varied from all isotropic to 50% forward, 50% backward.

## 2. DESCRIPTION OF AVAILABLE DATA

The data that are available for each reaction consist of the following:

- the total nonelastic cross section;
- the average number of cascade protons, neutrons,  $\pi^+$ -,  $\pi^0$ -, and  $\pi^-$ -mesons;
- the average number of neutrons, protons, deuterons, tritons,  $^3\text{He}$ , and alpha particles evaporated;
- the normalized angular distribution of each type of cascade particle for all energies of emission;
- the normalized energy spectrum of each type of cascade particle for all angles of emission;
- the average energy of emission of each type of cascade particle;
- the normalized energy spectrum for each type of evaporated particle;
- the first, second, and third moments of each evaporation spectrum;
- the cross section for the production of all residual nuclei at the completion of the evaporation process, i.e., the radiochemical cross sections for each reaction;
- $\frac{d^2\sigma}{d\Omega dE}$  (E) in mb/sr-MeV for cascade neutrons and cascade protons emitted into the angular intervals  $0-10^\circ$ ,  $10-30^\circ$ ,  $30-90^\circ$ , and  $90-180^\circ$ ;
- $\frac{d^2\sigma}{d\Omega dE}$  (E) in mb/sr-MeV for cascade  $\pi^+$ -,  $\pi^0$ -, and  $\pi^-$ -mesons emitted into the angular intervals  $0-25^\circ$ ,  $25-75^\circ$ ,  $75-130^\circ$ , and  $130-180^\circ$ ;
- the integral  $\int \frac{d^2\sigma}{d\Omega dE} dE$  for each angular interval;
- the average energy of emission into each angular interval;
- $\frac{d\sigma}{d\Omega}$  ( $\theta$ ) in mb/sr for three energy intervals, a low-energy interval, a midrange interval, and a high-energy interval, for all the cascade particles;

for each type of cascade particle, the cross section for the emission of  $n$  particles ( $n = 1, 2, \dots, 15$ ) into these three energy intervals;

$\frac{d\sigma}{d\Omega}(\chi)$  for the emission of two protons, where  $\chi$  is the angle between them;

the parallel and perpendicular momentum distributions of the residual nucleus at the completion of the cascade and the average value of each distribution;

the momentum distribution of the residual nucleus at the completion of the cascade and the average value of the distribution;

the excitation energy distribution of the residual nucleus at the completion of the cascade and the average value of the distribution;

the angular distribution of the residual nucleus at the completion of the cascade;

the average residual mass of the nucleus at the completion of the cascade;

the cross section for the emission of all combinations of cascade particles, i.e., the cross section for the emission of one cascade proton and nothing else, one proton and one neutron and nothing else, two protons and nothing else, etc.

For several selected combinations of emitted cascade particles, there are available all of the distributions above that refer to the residual nucleus at the completion of the cascade where the cascade reactions leading only to the emission of each specific combination contribute to each distribution.

The above data are available in microfiche form. All of the data for each case are on two microfiche. A case is a nuclear reaction involving one

type of incident particle at a specific energy on one target. Data from the Evaporation Code and Analysis Code I<sup>5)</sup> are on one microfiche and the data from Analysis Code II<sup>5)</sup> are on the other.

There are also available to users in the form of "history" tapes a description of the medium-energy cascade particles that escape from the nucleus and a description of the low-energy cascade particles, the latter tapes having been generated earlier<sup>2)</sup>. There is one case per tape, and these tapes may be written in 7-track or 9-track BCD form, as desired.

Upon request to the Radiation Shielding Information Center<sup>6)</sup>, users may obtain all of the data described above, i.e., the microfiche and the history tapes. In the latter case, requestors should send an appropriate number of reels of tape, and the data will then be copied onto these tapes.

### 3. PROGRAMS AVAILABLE

As previously mentioned, the preliminary version of the cascade calculation MECC-3 is available, along with the Evaporation Code, the Angular Momentum Code, Analysis Code I, Analysis Code II, and the Nuclear Configuration Code, described elsewhere<sup>5)</sup>. The Evaporation Code, the Angular Momentum Code, and the two analysis codes have been consolidated into one program called I4C. MECC-3, I4C, the Nuclear Configuration Code, and an instruction manual<sup>7)</sup> will be sent to interested users upon request to the Radiation Shielding Information Center<sup>6)</sup>. A reel of tape must accompany each request.

## REFERENCES

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